Characterizing Metal Brittleness

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In many applications, it is enough to specify where brittle behavior occurs so that it can be avoided; in welding, however, it may be necessary to pass through a region of brittle behavior. This can occur when metal grain boundaries remain liquid at temperatures substantially below the bulk melting temperature of the alloy, so that the metal is "hot short" or brittle below the bulk melting temperature. Even then, there might not be cause for concern if the hot metal were not subject to tensile stresses, but it is. Right after a weld pool solidifies, the environment heats up and expands. The expansion can pull apart microfissures (tiny cracks) in the heat-affected zone of the weld. Other crack morphologies, e.g., fusion line cracking, can result from other modes of brittle behavior.

To deal with welding cracking, in one way or another, one must be able to specify the level of abuse the metal can withstand inside its region of brittle behavior. Then it is possible to compare the tolerable abuse with the anticipated abuse to see whether defects will occur in the weld. While necessary, such measurements are not often made by those who characterize metal properties.

At MSFC, researchers have found it useful to represent the tolerable level of abuse of a metal in a regime of brittle behavior by a function relating the isothermal critical cracking strain, ε_C, to temperature, T. If the temperature coordinate is vertical, $\varepsilon_C(T)$ represents a nose-like curve resembling the "pearlite nose" on an isothermal phase-transformation diagram.

Strictly speaking, the isothermal critical cracking strain is also a function of time, $\varepsilon_C(T,t)$. Embrittling liquid boundaries eventually disappear as diffusive homogenization takes place. However, for the short times needed for welding solidification, the time effect may not be important. In fact, researchers have gotten reasonably good agreement between microfissuring predictions and data for a superalloy using an empirical function, $\varepsilon_C(T)$, obtained from observations of cracks and strains on the surface of a hot tensile test specimen.

As in the case of a hardening quench, where it is necessary to avoid the pearlite nose in order to form martensite, it is also necessary (in the vicinity of a weld) to avoid strains within the isothermal critical cracking strain regime as the metal cools from the melting temperature in order to avoid cracks. A means is required in each of the above cases to compare the isothermal values (times or strains) with the nonisothermal cool-down values. In the case of the cool-down strains, $\varepsilon(T,t)$, researchers chose a damage theory in which cracking was assumed to occur whenever:

$$\int \frac{d\varepsilon(T,t)}{\varepsilon_c(T)} = 1.$$

Although the damage theory seemed to work in microfissuring computations, a more clearly motivated cracking criterion is desirable, perhaps to emerge from an analysis of the mechanics of power absorption by various possible fracture modes. The form of the $\varepsilon_C(T)$ function used in the subject analysis was:

$$\varepsilon_c(T) = \varepsilon_{co} 2^{\left(\frac{GS-4}{2}\right)} e^{\frac{(T-T_G)^2}{B}}$$

where ε_{co}, T_G, and B are constants. GS represents the grain size and is incorporated into the expression to reflect the hypothesis that it is actually the displacement across a grain boundary that is critical, so that bigger grains that distribute a larger part of the overall strain to each grain boundary can tolerate less overall strain.

This kind of representation of data on the cracking tendency of an alloy is particularly useful in combination with an analysis yielding local strains. Current work is underway to predict the cracking of a light metal alloy as a function of weld process parameters, and to see whether an electron-beam raster pattern can be found to eliminate microfissuring in a superalloy.

Nunes, A.C., Jr. June 1983. Interim Report on Microfissuring of Inconel 718. NASA Technical Memorandum (TM–82531).

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